Naval Submarine Medical Research Laboratory

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Decompression Sickness Resulting From Long Shallow Air Dives

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Naval Medical Research and Development Command
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Summary Page

The Problem

The objective of this research was to provide human decompression data, including the occurrence and timing of resulting DCS cases, in a range of depths and bottom times which are inadequately represented in the Primary Air and Nitrogen-Oxygen (N_2-O_2) data set (Weathersby, et al. 1992).

The Findings

The occurrence of decompression sickness (DCS) was examined in 57 man-dives to depths between 8.5 and 12.2 msw (28 and 40 fsw) for six hours on air. During exposure, divers exercised using a bicycle ergometer at a moderate workload (100 watts) on a 50% work/50% rest cycle. After six hours bottom time, divers were immediately brought to the surface. Three DCS cases and two marginal DCS cases resulted from decompression from the deepest depths of 11.6 and 12.2 msw (38 and 40 fsw).

Application

The data from these and other dives were added to a master data base for diving at the Naval Medical Research Institute. This addition has allowed for further development of the probabilistic decompression model by providing the first available data in an important depth and bottom time range. The model's predictions of DCS risk for dives in this range are improved by the presence of these profiles in the calibration data set.

Administrative Information

This research was conducted under Naval Medical Research Work Unit 63713NM0099.01A-5201, Submarine related decompression problems. The views expressed in this report are those of the authors and do not reflect the official policy or position of the Navy, Department of Defense, or the U.S. Government. This report was approved for publication on 22 May 1996 and has been designated as NSMRL Report 1200.

Abstract

The objective of this research was to provide human decompression data, including the occurrence and timing of resulting DCS cases, in a range of depths and bottom times which are inadequately represented in the Primary Air and N_2-O_2 data set.

The occurrence of DCS was examined in 57 man-dives to depths between 8.5 and 12.2 msw (28 and 40 fsw) for six hours on air. During exposure, divers exercised using a bicycle ergometer at a moderate workload (100 watts) on a 50% work/50% rest cycle. After six hours bottom time, divers were immediately brought to the surface. Three DCS cases and two marginal DCS cases resulted from the deepest depths of 11.6 and 12.2 msw (38 and 40 fsw). The data from these and other dives were added to a master data base for diving at the Naval Medical Research Institute.

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DECOMPRESSION SICKNESS
RESULTING FROM LONG SHALLOW AIR DIVES

Decompression table development historically has been approached through simple table calculation, limited testing on very few profiles, and reiteration of table calculation. More recently, probabilistic modeling and maximum likelihood analysis (Weathersby, et al., 1984; Weathersby, 1989; Weathersby, et al., 1992) have been used. From these, improved assessment of decompression sickness (DCS) risk for proposed yet untested decompression schedules is possible.

Data from the past few years has been collected from a wide variety of dives. These data have been put into a master data base for decompression modelling (Weathersby, et al., 1992). With these data available for calibration, probabilistic models have been developed for bounce dives in the range of 3 to 64 meters sea water (msw) (10 to 210 feet sea water (fsw)) which include up to two hours of decompression stops (Weathersby, et al., 1992). Diving profiles which are not well represented in the data base have poorer predictive ability with the model. Long, non-saturated no decompression (no-D) dives (6-12 hours) at fairly shallow depths are an example of such dive profiles. The recent summary of the data base shows only 91 air dives conducted at 18.6 msw (61 fsw) in this bottom time category (Weathersby, et al., 1992).

One of the earlier probabilistic models (Hayes et al., 1986) predicted a 1.0% incidence of DCS risk following no-D dives to 5.8 msw (19 fsw), 5.0% DCS risk for dives to 8.5 msw (27.9 fsw), and 10% DCS risk for dives to 11.0 msw (36 fsw). Another model generated at the Naval Experimental Diving Unit (NEDU) (Thalmann, 1986), predicted that a diver could stay at 9.1 msw (29.9 fsw) for six hours, and then surface safely at the end of the dive.

The objective of this research was to provide data in a depth/bottom time range not yet represented in the data base. This was to be accomplished by: a) prediction of initial limits with existing models, b) performance of a test dive series using a sequential experimental design, and c) combination of test dives with other data for a robust prediction of limits.

Methods, Materials and Design

All dives were conducted dry in the "Genesis" hyperbaric chamber at the Naval Submarine Medical Research Laboratory (NSMRL) in Groton, Connecticut. Simulated depth was maintained within ± 0.15 msw (±0.5 fsw). Temperature and humidity were adjusted for subject comfort. Oxygen was continuously maintained at 20.94% (air) ±0.05%. Carbon dioxide was maintained at or below 0.5% surface equivalent.

All subjects were qualified military divers (active duty and reserve). Three to four subjects were used in each exposure. Divers refrained from all pressure exposure for at least three days before the experiment. Alcohol consumption and the taking of any drugs (including aspirin) were prohibited within 24 hours prior to the dive. Divers also abstained from any exercise the morning of the dive. Subjects were allowed to repeat an experiment, but not at the same depth. Any diver who suffered from DCS was not allowed to reenter the experiment until two weeks after completion of therapy. Divers were advised to neither dive nor fly for 36 hours after surfacing.

Six hours (including compression time of 1 to 7 minutes) were spent breathing air at simulated depths from 8.5 to 12.2 msw (28 to 40 fsw). During the exposure, subjects exercised on a bicycle ergometer at a paced rate of 67 revolution per minute (rpm) and a workload of 100 watts on a 30 minutes work/30 minutes rest cycle for a total of four exercise periods (two hours work total). After the six hour bottom time, an immediate ascent to the surface was made at a rate of 7.6 to 18.3 msw (25 to 60 fsw) per minute (average rate of 17 msw (55.8 fsw) per minute), except for 6 exposures at 8.5 msw (28 fsw) which reached the surface in 3 minutes.

Decompression Monitoring

A qualified Diving Medical Officer (DMO) made a diagnosis in accordance with conventional diagnostic categories (NAVSEA, 1987). Evaluation of subjects was based both on spontaneous reporting of symptoms and post-dive medical examinations. All divers were examined immediately after surfacing, about two hours after surfacing, and again 24 hours after surfacing. All divers were strongly encouraged to report any unusual feelings, regardless of whether or not they appeared to be dive related. When a diagnosis of DCS was made, appropriate treatment was immediately initiated (NAVSEA, 1987). Treatment table extension was performed as required.

Sequential Design

The experimental series started with dives to a depth of 8.5 msw (28 fsw) for six hours. If no DCS occurred in at least ten man-dives, then the depth was increased by 1.2 msw (4 fsw), and ten additional man-dives were conducted. If two cases of DCS occurred in any number of man-dives at a given condition, then the depth was decreased by 0.6 msw (2 fsw). The test protocol was sequentially repeated following the same decision rules.

Results

A total of 57 man-dives were conducted with 50 different divers (49 males and 1 female, mean age = 26.7 years). Five divers performed a total of two dives and one diver performed a total of three dives. None of the repeat divers suffered DCS. Table 1 outlines the incidence of DCS and marginal DCS for these dives. Marginal cases are considered minor decompression-related problems that are not diagnosed as DCS but represent unusual feelings or fleeting pains that occur following a dive (Table 1).

Table 1.
Incidence of DCS and Marginal DCS cases following shallow 6 hr air dives

Depth msw/fsw	N	Cases DCS	Cases Marginals
8.5/28	10	0	0
9.8/32	11	0	0
11.0/36	11	0	0
11.6/38	10	1	1
12.2/40	15	2	1

Three treated cases and two marginal cases of DCS resulted from the entire series. These decompression problems occurred following dives to the two deepest depths, 11.6 and 12.2 msw (38 and 40 fsw). Following treatment, divers with DCS had complete resolution of DCS symptoms, with no residuals.

The first case of DCS occurred in a 29 year old male following a 11.6 msw (38 fsw) exposure. Approximately 2 hours after surfacing, the subject developed severe throbbing left retro-orbital pain. He had a history of cluster headaches, usually precipitated by alcohol and fatigue, and this headache was not different than those previously experienced. The headache resolved within 3 hours and the subject slept comfortably. At 65 hours post-dive, the diver noted the sudden onset of left hip pain, made much worse with weight bearing. The pain was described as "deep-seated" and "within the hip joint." There was not a history of recent trauma or previous hip pain. The pain progressed over a 1 to 2 hour period to the point where the subject was unable to bear weight on the left leg (10 out of 10 in severity). There were no other complaints. Examination of the left hip revealed no erythema or swelling. Slight tenderness was elicited with palpation of the greater trochanter. Range of motion of the affected hip was limited, especially abduction and extension. Strength was decreased secondary to pain. Sensation in the left leg was intact. Deep tendon reflexes in the lower extremities were 3+ and equal bilaterally. The subject was unable to bear weight on the left leg. The remainder of the neurological and general physical examination were normal. An x-ray of the left hip was normal. Although the symptoms occurred very late post-dive, there was no other clear explanation for the severe pain and loss of function. The subject was compressed to 18.3 msw (60 fsw) on oxygen and had a 50% reduction in pain (now 5/10) after the first 20 minute oxygen breathing period. Symptoms continued to decrease in severity and were essentially resolved after a total of 5 oxygen breathing periods at 18.3 msw (60 fsw). The U.S. Navy extended Treatment Table 6 (TT6) was completed without complication and on surfacing, the subject had only mild residual left hip soreness. Post-treatment examination was normal. The soreness slowly resolved over the next 3 to 5 days.

The second case of DCS occurred following a dive to 12.2 msw (40 fsw). The subject, a 30 year old male, reported right shoulder pain approximately 1 hour 5 minutes after surfacing. The pain was described as poorly localized with an intensity of 2 out of 10 which increased to 3/10 during the first few minutes of the DMO examination, then gradually decreased. Two hours and 20 min. after surfacing, the subject was treated on a TT6. Following the second 20 minute O_2 breathing period (with 5 min air breathing between O_2 periods) at 18.3 msw (60 fsw), the patient reported prior fleeting left shoulder pain that he stated occurred during pressurization but resolved quickly at approximately 7.6 msw (25 fsw) on descent. The patient also reported being free of symptoms after this time. The standard TT6 was completed with no residual problems after treatment.

The third case of DCS encountered occurred after a 12.2 msw (40 fsw) dive. At 2 hours and 10 minutes post dive a 32 year old male complained of mild left posterior knee stiffness. He stated it began approximately 10 minutes after surfacing but that the discomfort had not progressed. The diver also complained of minor neck "stiffness." Examination of the left knee, left leg, and neck were normal. At about 3.5 hours after surfacing, the diver noted a dull pain in his left hand between the fourth and fifth metacarpal. He also described dull pain in both the left triceps and left trapezius muscles. The neck discomfort persisted and intermittently radiated to his left arm. A variety of additional symptoms noted included

transient left ankle and left foot pain, brief periods of light-headedness, and short episodes of a "cold, clammy feeling all over." These additional symptoms resolved prior to treatment. At 5 hours post-dive, the subject complained only of pain in the left hand, left triceps and left trapezius muscles. The severity was graded 2/10. The neck stiffness persisted. Neurological examination, including motor, sensory, and cerebellar testing, was normal. A diagnosis of neurological DCS was made, and the subject was compressed to 18.3 msw (60 fsw) on 100% oxygen. He noted complete resolution of all muscular pain and neck stiffness 10 minutes into the first oxygen breathing period. Left hand stiffness was relieved 20 minutes into the first oxygen period. A TT6 was completed without complication. Examinations immediately after treatment and on the following day were normal.

The first marginal DCS case occurred 10 hours after surfacing from a dive to 11.6 msw (38 fsw). The case involved a male diver (age = 33 years) who had fleeting minor pain in his right wrist and left elbow which was not sustained nor well defined. All symptoms were gone by 16 hrs post-dive without treatment.

The second marginal DCS case occurred 18 hours and 40 minutes after surfacing from a dive to 12.2 msw (40 fsw). This case also involved a male diver (age = 30 years) who had transient and intermittent pain in his left knee. About 45 minutes after surfacing all symptoms were gone and no treatment was necessary.

Discussion

No cases of DCS resulted from dives to depths of 8.5, 9.8, and 11.0 msw (28, 32, and 36 fsw). The incidence of DCS was 10.0% for dives to 11.6 msw (38 fsw) and 13.3% for dives to 12.2 msw (40 fsw). These results however, are of limited use because of the small number of replicate exposures at each depth. Decompression testing having a substantial degree of confidence is not practical since the number of replicate exposures needed for a single dive profile is very large. For example, to be 95% confident that the

Table 2.
Predictions of DCS incidence for 6 hour dives

	Model Predictions (Parker, et al., 1992)		
	Avg %	(95% Confidence Limits)	
msw/fsw	DCS	Lower	Upper
8.5/28	4.04	2.44	5.62
9.8/32	5.26	3.91	7.57
11.0/36	7.52	5.42	9.58
11.6/38	8.50	6.25	10.70
12.2/40	9.42	7.04	11.76

underlying incidence of DCS risk is less than 10%, one would need to conduct 54 man-dives per profile and encounter only one case of DCS. Conducting a large number of man-dives is theoretically possible, but it is also economically unfeasible. A more practical alternative is to use a large collection of exposures from a variety of dives performed at various laboratories to allow quantitative extrapolation into other risk conditions (Weathersby, et al., 1984).

One such probabilistic model reported in 1992 (Parker, et al.,) was used to predict DCS risk for the shallow 6 hour dives of this study (Table 2). This model predicted 4.0, 5.3, 7.5, 8.5, and 9.4% DCS for dives to 8.5, 9.8, 11.0, 11.6, and 12.2 msw (28, 32, 36, 38, and 40 fsw), respectively.

The addition of new data to the master data base should improve predictions for untested long shallow bounce dive scenarios. As this database grows with the addition of data from similar dives, no-D limit predictions for non-saturation bounce dives will become more accurate. As DCS risk predictions improve, planned management of those risks becomes more quantitative.

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